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(54) UV detector and method for fabricating it.

(57) A method of preparing a UV detector of $Al_xGa_{1-x}N$. Metal organic chemical vapor deposition (MOCVD) is utilized to grow AlN and then $Al_xGa_{1-x}N$ on a sapphire substrate. A photodetector structure is fabricated on the AlGaN.

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UV Detector and Method for fabricating it

This invention is directed to a process of fabricating a solid-state UV detector and to detectors obtained by such process.

It is known to have photocathodes and photomultiplier-tubes (PMT's) which sense ultraviolet (UV) radiation. The PMT's are costly, large size and fragile, and they require high voltage. In addition the long wavelength cut-off of these detectors is not adjustable and they respond to wavelengths longer than 30nm. Filters can be used to reject wavelengths longer than 30nm but this adds mass and cost.

In the prior art certain UV detectors of $Al_xGa_{1-x}P$ have appeared in the literature. Two of these articles are by the same authors A. R. Annoeva et al, "Photoelectric Effect in Variable-Gap $Ga_{1-x}Al_xP$ Surface-Barrier Structures", Sov. Phys. Semicond. 15(1) Jan. 1981, P. 64-66 and "Ultra-violet Photodetector Based on a Variable-Gap $Ga_{1-x}Al_xP_x$ (x_s=0.5+0.1) Surface Barrier Structure", Sov. Phys. Semicond. 15(6) June 1981, P. 646-7. These prior art AlGaP devices were grown by liquid phase epitaxy (LPE). A third article dated Feb. 1981 written by Donald L. Smith and Richard H. Bruce, entitled "Grown of Aluminum Gallium Nitride Films for Electro-optic Device Applications" is an unrestricted but unpublished report to the Office of Naval Research. An article by Khan et al, "Properties of Ion Implantation of $Al_xGa_{1-x}N$ Epitaxial Single Crystal Films Prepared by Low Pressure Metal Organic Chemical Vapor Deposition", Appl. Physics Letters, Sept. 1983 teaches one method by which $Al_xGa_{1-x}N$ has been grown on a sapphire substrate for use as an optical device in the UV region of the spectrum.

It is an object of the invention to provide an improved method of growing an AlGaN sensor for ultraviolet radiation which solves the problem of detecting UV radiation against a hot refractory background or solar radiation. This detector responds only to the UV and not to radiation of other wavelength emanating from the hot furnace interior. These and other objects are achieved by the new solid state UV detector as described in claim 7 which preferably can be fabricated by the method as described in claim 1. Preferred embodiments of the detector and fabricating steps of the process are disclosed in the subclaims. This UV-detector is based on interband absorptions of incoming radiation in an aluminium gallium nitride (AlGaN) material system. The detector does not require any additional filter as the intrinsic absorption cutoff in the semiconductor acts as a filter. The long wavelength cut-off can be set between 220 and 360nm for flame sensing and other applications. The solid-state AlGaN detector of this invention is an ideal replacement for the PMT's having low mass, reliability, low cost and has a sharp cutoff wavelength for UV detection. The method includes a metal organic chemical vapor deposition (MOCVD) process for first growing a layer of AlN on the sapphire substrate and then the AlGaN layer upon which a photodetector structure is fabricated. The single drawing is a diagrammatic view of the UV detector made according to the method of the invention. A solid-state Aluminum Gallium Nitride ($Al_xGa_{1-x}N$) UV detector and the process of fabricating the device will be described. In order to have a sharp wavelength cut-off feature the active laser material should be a single crystal semiconductor in which direct intrinsic bandgap absorption sets in very abruptly. The $Al_xGa_{1-x}N$ system is the preferred choice because it has wide bandgaps which lie in the ultra violet range of energies and because the spectral response can be tuned or tailored to the application by

varying the aluminum to gallium ratio. Thus AlGaN will be grown by MOCVD in the compositional range required to produce detectors having peak sensitivities between 3.53eV(350nm) and 4.64eV(267nm). The MOCVD process is well adapted (unlike halide transport vapor phase epitaxy) to the growth of aluminum-gallium alloy systems because the ratio of aluminum to gallium can be easily controlled.

For the absorbed photons to be detected electrically, the electrons and holes produced must be separated before they recombine. This is conveniently accomplished by drift in an electric field such as that provided by a Schottky barrier or photoconductor approach. The Schottky barrier metal-semiconductor junction results in a depletion region in the AlGaN semiconductor in which the photogenerated electrons and holes are separated by the built-in electric filed which may be augmented if desired by an applied bias. In the forming of this function the doping of the semiconductor is important. If the AlGaN material is too heavily doped n-type ($\sim 10^{18} cm^{-3}$), the depletion layer will be very narrow, and tunneling of electrons to the semiconductor through the Schottky barrier will lead to leakage current or to a ohmic contact instead of a good Schottky barrier contact. If the doping is too low, that is if the Fermi level lies greater than several kT

below the conduction band, the bulk material will be highly resistive. In the AlGaN system, to form a good Schottky barrier requires a net shallow donor concentration on the order of $10^{16}cm^{-3}$.

Referring now to the figure there is shown a solid-state solar blind UV detector 10 having a basal plane sapphire (Al_2O_3) substrate 11. In preparing the device the substrate is loaded into a metalorganic chemical vapor deposition (MOCVD) reactor and heated such as by rf induction to 1000°C. Then NH_3 and $(CH_3)_3Al$ (trimethylaluminum) or $(C_2H_5)_3Al$ (triethylaluminum) are introduced into the growth chamber and epitaxial growth continues for about 10 minutes resulting in a single crystalline aluminum nitride (AlN) layer 12 about 0.5μm thick on the surface 13 of the substrate. The buffer layer 12 of AlN results in a higher electron mobility of the epitaxial $Al_xGa_{1-x}N$ layer to be next grown thereon. Then triethylgallium $(C_2H_5)_3Ga$ is also introduced into the growth chamber and the epitaxial growth of the aluminum gallium nitride ($Al_xGa_{1-x}N$) is carried out for about 2 hours. This results in a single crystalline aluminum gallium nitride ($Al_xGa_{1-x}N$) layer 14 on the order of 2μm thick. The x value selected can be controlled as desired by adjusting the gas flow rates of the several gases. The temperature during $Al_xGa_{1-x}N$

growth is lowered from the 1000°C and is selected depending upon the x value selected. In one embodiment we grow the active $Al_xGa_{1-x}N$ layer with an x value of about 0.35 which puts the cutoff wavelength at 290nm. The $Al_xGa_{1-x}N$ layer as grown is n type with $N_d \sim 5x10^{16}/cc$.

A metal Schottky barrier 15 is fabricated on the AlGaN layer. For fabrication of the Schottky barrier 15 and the ohmic contact 16 onto the surface 17 of the $Al_xGa_{1-x}As$ layer 14, the surface 17 is masked to delineate contact 16 and a layer of 3000A of gold or other suitable metal is first deposited for contact 16 and is then annealed at 700°C under flowing NH_3 for 5 min. The surface 17 is again masked with photoresist to delineate the Schottky barrier location. Then for barrier 15 there is applied onto surface 17 Au/TiW/Au (100Å/1000Å/5000Å) using for instance an rf-sputtering system. In this particular Schottky metallization, the TiW acts as a diffusion barrier for the 5000Å layer of gold.

Attached to the device 10 at Schottky barrier 15 and ohmic contact 16 is a series circuit including conductors 18 and 19, dc source such as battery 20 and a current meter 21 for measurement of the resulting photocurrent.

In operation the Schottky barrier is kept under reverse bias (e.g. 2 to 3V) so that only a leakage current flows in the external circuit. When a photon (UV light from the flame) enters the depletion region under the Schottky barrier through the transparent Al_2O_3 substrate (typically 1mm thick) an electron-hole pair is created. That is, when a UV photon with an energy E>Eg (Eg is the bandgap energy for $Al_xGa_{1-x}N$) is incident on the active layer it creates electron-hole pairs which are swept out by the electric field and hence a signal current is detected in the external circuit. The signal curent is only produced when the UV-photon is absorbed in the active layer, and thus the device shows a response which turns on very sharply at a wavelength determined by the bandgap of the active $Al_xGa_{1-x}N$ layer.

While the apparatus has been shown and described as being negatively biased for operation, it can also be operated in a zero-bias photovoltaic mode which makes it fail-safe as no signal is possible except under UV illumination.

The electron-hole pairs and hence the signal current is only produced if the wavelength of incident light is less than or equal to g where g = hc/Eg where "h" is the Planck's constant, "c" the velocity of light and "Eg" is the bandgap of the semiconductor $Al_xGa_{1-x}N$. Another kind of photodetector structure,

a photoconductor can also be used. In this both metal contacts 15 and 16 are ohmic contacts and a source of electric field bias is required.

Claims:

1. A method for fabricating by metal organic chemical vapor deposition (MOCVD) a solid-state UV detector comprising the steps of:
   a) loading a basal plane sapphire (Al_2O_3) substrate into a MOCVD reactor growth chamber;
   b) heating said reactor growth chamber to about 1000°C;
   c) introducing NH_3 and an aluminum containing metal organic compound into said heated growth chamber to grow a AlN buffer layer on the order of 0.5µm thick on the Al_2O_3 substrate;
   d) further introducing a gallium containing metal organic compound into said heated growth chamber as well as the NH_3 and aluminum containing metal organic compound for a period sufficient to grow over the AlN layer a $Al_xGa_{1-x}N$ layer having the desired x value; and,
   e) fabricating a photodetector structure on said $Al_xGa_{1-x}N$.

2. The method according to claim 1, characterized in that said aluminum containing metal organic compound is trimethyl-aluminum $(CH_3)_3Al$.

3. The method according to claim 1, characterized in that said aluminum containing metal organic compound is triethyl-aluminum $(C_2H_5)_3Al$.

4. The method according to claim 1, characterized in that said gallium containing metal organic compound is triethyl-gallium $(C_2H_5)_3Ga$.

5. The method according to one of the claims 1 to 4, characterized in that the photodetector structure is a Au-TiW-Au Schottky barrier.

6. The method according to one of the claims 1 to 4, characterized in that the photodetector structure is a photoconductor.

7. A solid state UV detector comprising:
   a) a basal plane sapphire (Al_2O_3) substrate (11);
   b) an epitaxial single-crystalline aluminum nitride (AlN) layer (12) grown on the surface of the substrate;
   c) an epitaxial single-crystalline aluminum gallium nitride ($Al_xGa_{1-x}N$) layer (14) grown over said AlN layer; and,
   d) a photodetector (15) fabricated on said $Al_xGa_{1-x}N$ layer surface.

8. The detector according to claim 7, characterized in that the AlN layer is on the order of 0.5μm thick.

9. The detector according to claim 7 or 8, characterized in that the $Al_xGa_{1-x}N$ layer is on the order of 2μm thick.

10. The detector according to one of the claims 7 to 9, characterized in that said photodetector is a Schottky barrier.

11. The detector according to claim 10, characterized in that said Schottky barrier comprises layers of Au, TiW and Au.

12. The detector according to one of the claims 7 to 9, characterized in that said photodetector is a photoconductor.